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Planktonic Larval Duration, Settlement, and Growth Rates of the Young-of-the-Year of Two Sand Basses (*Paralabrax nebulifer* and *P. maculatofasciatus:* fam. Serranidae) from Southern California

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Abstract.—Accurate estimates of Planktonic Larval Duration (PLD) have become critical to the modeling of larval dispersal and connectivity among ecological communities. Among those species where little information on larval duration is known are the spotted (*Paralabrax maculatofasciatus*) and barred (*P. nebulifer*) sand basses, two economically important species that have historically been the focus of marine recreational fisheries off southern California. PLD was determined by a count of the daily growth rings from the otolith core to the settlement check and age from the core to the otolith margin. Size at settlement was estimated by the size of the otolith from its core to the settlement mark based on the otolith size to body size relationship. Based on these significant relationships, mean size at settlement of our specimens was calculated to be 10.2 ± 1.6 mmSL for spotted sand bass and 9.1 ± 1.1 mmSL for barred sand bass. Mean PLD was 32.8 ± 2.2 days with a range from 28 to 37 days for spotted sand bass and 25.8 ± 2.2 days (range 21–30) for barred sand bass. Growth rates for the YOY of each species estimated by calculating the length-to-age relationships were 1.13 mm/day for spotted sand bass and 1.28 mm/day for barred sand bass. PLDs of approximately one lunar month and growth rates of about 1 mm/d seem to be common in those summer spawning fishes from San Diegan Province (warm temperate).

Introduction

In recent years, accurate estimates of planktonic larval duration (PLD) have become critical to the modeling of larval dispersal and connectivity among ecological communities (Miller and Shanks 2004, Levin 2006, Shanks 2009, Shanks and Eckert 2005, Cowen and Sponaugle 2009, Watson et al. 2010, Watson et al. 2011). Such studies, particularly on fishes, are often limited by the lack of PLD information, even on ecologically and economically dominant species off California (Shanks and Eckert 2005).

Among those species where little information on larval duration is known are the spotted (*Paralabrax maculatofasciatus*) and barred (*P. nebulifer*) sand basses, two economically important species that have historically been the focus of marine recreational fisheries off southern California. Both are warm temperate serranids with spotted sand bass ranging from Monterey, California south to Mazatlan, Mexico including the Gulf of California and barred sand bass occurring from Santa Cruz, California south to Todos Santos (23°23′N, 110°12′W), including Guadalupe Island (Miller and Lea 1972). In southern California, the spotted sand bass is restricted to shallow, warm-water areas such as lagoons, bays, and harbors where structure in the form of eel grass and rock relief occurs (Allen et al. 1995), whereas barred sand bass mainly inhabits the open coast near structure to depths of about 40 m (Hovey et al. 2002).

Aside from developmental studies based largely on laboratory reared specimens (Butler et al. 1982), little information exists on early life history in regards to PLD, settlement size, and daily growth rates of young-of-the year (YOY) of either of these two species.

Since the initial application of daily growth rings in the aging of larval fishes by Brothers et al. (1976), numerous studies have proven the validity and usefulness of this technique in the investigation of early life history characteristics (for reviews, see Campana and Neilson 1985). Spawning and settlement (Middaugh 1981, McFarland et al. 1985, Cordes and Allen 1997), growth rates (Geffen 1982, Neilson and Geen 1982), and planktonic duration (McFarland et al. 1985, Victor 1986) have all been studied using daily growth increments. The settlement check may be a result of the stress associated with a transition from a planktonic to a demersal life style, during which a change in growth or metabolic rate is recorded as a change in the deposition rate of the rings, resulting in the check (Gauldie 1991).

The purpose of this study was to examine aspects of the early life history of spotted sand bass and barred sand bass by using daily growth ring and settlement check analysis of young-of-the-year (YOY) specimens. Specifically, we estimate 1) planktonic larval duration (PLD), 2) age and length at settlement, and 3) average daily growth rates of these juvenile sand basses.

Methods

The YOY sand basses examined in this study were collected at two southern California locations at two separate times. The 27 juvenile spotted sand bass were from Agua Hedionda Lagoon (33°08′33″ N; 117°19′39″ W) and collected as a result of a single heat treatment at Encina Power Plant, in Carlsbad, CA on April 11, 2005 by the Vantuna Research Group of Occidental College. The 57 juvenile barred sand bass were collected using beam and otter trawls in San Diego Bay, CA (32°39′00″ N; 117°08′03″ W) over the period of October 1997 to April 1999 during California State University Northridge's (CSUN) fisheries utilization study for the U.S. Department of the Navy (Allen et al. 2002). All specimens were frozen and returned to CSUN (California State University, Northridge) for future workup.

In the laboratory, all of the fish were thawed, blotted dry, weighed to the nearest hundredth of a gram, and measured for standard length (SL) to the nearest tenth of a millimeter using calipers. For the barred sand bass some specimens, n = 33, whose otoliths had been previously extracted, were only measured to the nearest tenth of a gram and SL was measured to the nearest millimeter. After being weighed and measured, the sagittal otoliths were removed from all individuals. Otoliths were then mounted on glass slides sulcus-side down and polished using 3 um sand paper until daily bands near the core were visible. Otoliths were then covered in immersion oil for age and size determination. All measurements were completed using a compound microscope, camera, and image analysis software (Image-Pro Plus). Settlement checks, identified as abrupt changes in the width of daily bands at the time of settlement, were found in all specimens examined. PLD was determined by a count of the daily growth rings from the core to the settlement check. Size at settlement was estimated by the size of the otolith from the core to the settlement mark based on the otolith size to body size relationship.

Daily growth rings were double read on each otolith, and if readings were more than 10% different they were read a third time. If after the third reading, two of the three readings were still not within 10% of each other, that individual was not included in this

Table 1. Estimated Plankton Larval Duration (PLD) and size at settlement for the three species of *Paralabrax* from southern California.

Species	Planktonic Larval Duration Range (d)	Planktonic Larval Duration Mean ± STD (d)	Settlement Size (mmSL)	N	Data Source(s)
Paralabrax maculatofasciatus	28–37	32.8 ± 2.2	10.2 ± 1.6	27	present study
Paralabrax nebulifer	21–30	25.8 + 2.2	9.1 ± 1.1	51	present study
Paralabrax clathratus	25–32	28.8 ± 2.3	9.4 ± 0.7	14	McClean 1999

analysis. If the two readings were within 10% of one another, then the mean of the two readings was used in statistical analyses.

Validation of daily growth rings in the genus *Paralabrax* was accomplished and presented in Cordes and Allen (1997) in their study on the closely related congener, the kelp bass (*P. clathratus*). Cordes and Allen (1997) also determined that daily ring deposition began on the third day of life. Therefore, two days were added to each ring count in all age estimates in spotted sand bass and barred sand bass. This correction accounts for the delay in daily growth ring formation in the larval otolith before yolk absorption.

Age (days) and length (mmSL) relationships in these young stages were examined by correlation and were modeled by linear regression. Both settlement age and size at settlement were determined independently for each specimen. The measurement of settlement age was based on the pre-settlement ring count (+ 2 days), and size at settlement was based on the otolith radius to somatic length regression from measured standard length. Due to the independent determination of these measurements we felt justified in using the size and age at settlement data to "anchor" the regression line for each species. This procedure effectively doubled the sample sizes and greatly enhanced the fit to the predictive growth models. All statistics, calculations, and graphics were prepared using Excel 2007 (version 12, Microsoft Corp.), and Statistica (version 10, StatSoft, Tulsa OK).

Results

In these two species, as well as many others, otolith size is closely related to the body size of the individual. In this study, predictably, a strong linear relationship existed between otolith radius and standard length for both species (spotted sand bass, $n = 27$, $R^2 = 0.91$, $p < 0.0001$; barred sand bass, $n = 51$, $R^2 = 0.93$, $p < 0.0001$). Based on these significant relationships, mean size at settlement of our specimens was calculated to be 10.2 ± 1.6 mm SL for spotted sand bass and 9.1 ± 1.1 mm SL for barred sand bass. Mean PLD was 32.8 ± 2.2 days with a range from 28 to 37 days for spotted sand bass and 25.8 ± 2.2 days (range 21–30) for barred sand bass (Table 1).

Likewise, the age to length relationships for the YOY of both species were highly significant. The age-to-length relationship of spotted sand bass was best described by the linear equation: $A = 0.87L + 24.01$ ($R^2 = 0.98$) where A = age in days and L = standard length in mm (Figure 1A). Age to length in YOY barred sand bass was also similarly described by the linear relationship: $A = 0.74L + 19.66$ ($R^2 = 0.95$) (Figure 1B).

Growth rates for the YOY of each species were estimated by calculating the length-to-age relationships (Table 2). The significant length-to-age regression equation was calculated as: $L = 1.13(A) - 26.34$ ($R^2 = 0.98$) for spotted sand bass and $L = 1.28(A) - 23.43$ ($R^2 = 0.95$) for barred sand bass. Therefore, YOY growth rates for these samples, as

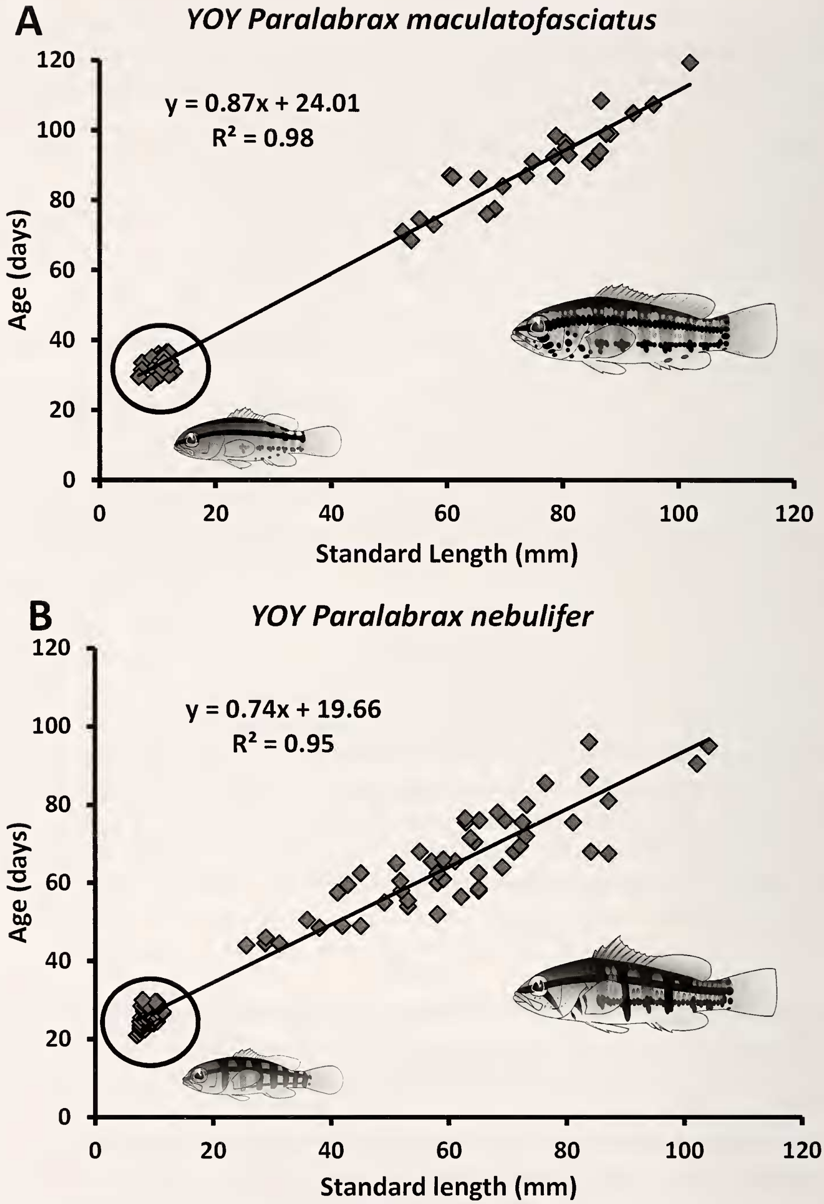

Fig. 1. Relationship of age (days) to standard length (mmSL) in YOY *Paralabrax maculatofasciatus* (A) and *P. nebulifer* (B) including age and independently derived (back calculated) size at settlement estimates (indicated by black circles) from otolith radius measurements.

indicated by the slopes of the lines, were 1.13 mm/day for spotted sand bass and 1.28 mm/day for barred sand bass.

Discussion

PLD, age and size at settlement for the two sand basses in this study were remarkably similar to those estimated for their congener the kelp bass. All three *Paralabrax* are

Table 2. Estimated young-of-the-year (YOY) length-age relationships and growth rates (mmSL/d) of the three species of *Paralabrax* from southern California.

Species	YOY Length (mmSL) to Age (d)	YOY Age (d) to Length (mmSL)	R^2	Growth rate (mmSL/d)	Size Range (mmSL)	N	Data Source(s)
Paralabrax maculatofasciatus	L = 1.13(A) − 26.34	A = 0.87(L) + 24.01	0.984	1.13	7–102	54	present study
Paralabrax nebulifer	L = 1.28(A) − 23.43	A = 0.74(L) + 19.66	0.949	1.28	7–104	102	present study
Paralabrax clathratus	L = 0.41(A) − 2.01	A = 2.16(L) + 8.15	0.875	0.41	8–40	127	Cordes 1992, McClean 1999

summer spawners and PLD for all three were approximately a lunar month (28 d) with size at settlement centered near 10 mm SL (Table 1). Interestingly two additional economically important, broadcast spawning fishes from southern California have also been shown to have PLD at or near the lunar month including the California halibut (*Paralichthys californicus*, PLD = 27.9 ± 4.0 d, Sears-Hartley 1994) and white seabass (*Atractoscion nobilis*, PLD = 29.1 ± 2.4 d, Donohoe 1997).

Sears-Hartley (1994) estimated that California halibut, a spring to early summer spawning species, settled at similar sizes (8.6 ± 1.2 mm SL) to those of the three *Paralabrax* in the waters off southern California. However, white seabass, also a summer spawning fish, appears to settle along the open coast at smaller sizes (7.3 ± 1.5 mm SL) than the three *Paralabrax* species and California halibut off southern California (Donohoe 1997).

Shanks et al. (2003) presented slightly different PLD estimates for two of the species mentioned above. They reported a PLD for white seabass of 32 d with a range of 29–35 d based on samples taken from the northern portion of the Southern California Bight (Franklin 1991, Allen and Franklin 1992). This estimate of PLD was slightly higher than that estimated by Donohoe (1997) from specimens captured in the southern portion of the Bight. The estimate of a PLD for spotted sand bass of 22 d ranging from 17–27 d was based on earlier work on fishes collected in Magdalena Bay, Baja California Sur, Mexico. Our recalculation of this previous estimate of PLD was 21 d (20.8 ± 3.5) for spotted sand bass from near the southern end of their range was significantly lower than that presented for spotted sand bass from southern California near the northern end of their range. The corresponding size at settlement (13.5 + 0.1 mm SL) of the Magdalena Bay YOY was higher indicating faster growth in warmer waters of this southern locale (J.T.W. Smith and L.G. Allen, unpub. data).

Our estimates of age at settlement for the *Paralabrax* species compare favorably to the minimum age at transformation of laboratory reared specimens presented in Butler et al. (1982). In their study, the earliest transformed individuals were 28 days for all three species of *Paralabrax*. Sizes at transformation were reported as total body length (mm TL) and once converted to mm SL tended to be slightly less than the sizes reported for field caught specimens in the present study. According to Butler et al. (1982), kelp bass reared in the laboratory at 19 °C first transformed at 8.0 mmSL (compared to 9.4 mm SL reported here). Spotted sand bass reared at 21 °C first transformed at about 8.0 mm SL (compared to 10.2 mm SL), and barred sand bass also at 21 °C first transformed at about 9 mm SL which was comparable to the 9.1 mm SL found in the current study.

From our current data, after settlement, YOY spotted sand bass grew at 1.13 mm/day while YOY barred sand bass grew slightly faster at 1.28 mm SL/d off southern California. These rates are over 2-times higher than that of the YOY kelp bass, which were estimated to grow at approximately 0.41 mm/day (recalculation using data from Cordes 1992 and McClean 1999). Prior to settlement, larvae of both sand bass species only grew at a much slower rate of approximately 0.3 mm/day. We should also note that the age-to-length regression model for YOY kelp bass reported herein was based on specimens up to 40 mm SL (A = 2.16(L) + 8.15, Table 2) and is a recalculation of that found in Cordes and Allen (1997) where the reported age-length model was found to be in error.

In closing, we offer the simple observation that PLDs of approximately one lunar month and growth rates of about 1 mm/d seem to be common in those summer spawning fishes from San Diegan Province (warm temperate) that have been studied thus far.

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Literature cited

Allen, L.G. and M.P. Franklin. 1992. Abundance, distribution, and settlement of young-of-the-year white seabass, *Atractoscion nobilis*, in the Southern California Bight, 1988–1989. U.S. Fish. Bull., 90: 633–641.

———, T.E. Hovey, M.S. Love, and J.T.W. Smith. 1995. The life history of the spotted sand bass (*Paralabrax maculatofasciatus*) within the Southern California Bight. CalCOFI Rep., 36:193–203.

———, A.M. Findlay, and C.M. Phalen. 2002. The fish assemblages of San Diego Bay in the five-year period of July 1994 to April 1999. Bull. So. Cal Acad. Sci., 101(2): 49–85.

Brothers, E.B., C.P. Mathews, and R. Lasker. 1976. Daily growth increments in otoliths from larval and adult fishes. U.S. Fish. Bull., 74(1): 1–8.

Butler, J.L., H.G. Moser, G.S. Hageman, and L.E. Nordgren. 1982. Developmental stages of three California sea basses (*Paralabrax*, Pisces, Serranidae). CalCOFI Rep., 23:252–268.

Campana, S.E. and J.D. Neilson. 1985. Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci., 42: 1014–1031.

Cordes, J.F. 1992. Age, growth, spawning periodicity, settlement, and distribution of young-of-the- year and older juvenile kelp bass (*Paralabrax clathratus*) in the Southern California Bight during 1988-90. Master's thesis, California State University, Northridge. 91 pp.

——— and L.G. Allen. 1997. Estimates of age, growth, and settlement from otoliths of young-of-the-year kelp bass (*Paralabrax clathratus*). Bull. So. Cal. Acad. Sci., 96(2): 43–60.

Cowen, R.K. and S. Sponaugle. 2009. Larval dispersal and marine population connectivity. Ann. Rev. Mar. Sci., 1:443–466.

Donohoe, C.J. 1997. Age, growth, distribution, and food habits of recently settled white seabass, *Atractoscion nobilis*, off San Diego, California. U.S. Fish. Bull., 95:709–721.

Franklin, M.P. 1991. Abundance, distribution, age determination, and growth of young-of-the-year white seabass, *Atractoscion nobilis*, in the southern California Bight, 1988 and 1989. Master's thesis, California State University, Northridge. 126 pp.

Gauldie, R.W. 1991. The morphology and periodic structures of the otolith of the Chinook salmon (*Oncorhynchus tshawytscha*), and temperature-dependent variation in otolith microscopic growth increment width. Acta Zool. (Stockholm), 72(3): 159–179.

Geffen. A.J. 1982. Otolith ring deposition in relation to growth rate in herring (*Clupea harengus*) and turbot (*Scophthalmus maximus*) larvae. Mar. Bio., 71:317–326.

Hovey, C.B., L.G. Allen, and T.E. Hovey. 2002. The reproductive pattern of barred sand bass (*Paralabrax nebulifer*) from southern California. CalCOFI Rep., 43:174–181.

Levin, L.A. 2006. Recent progress in understanding larval dispersal: new directions and digressions. Integr. Comp. Biol., 46:282–297.

McClean. A.M. 1999. Settlement patterns of a temperate reef fish, *Paralabrax clathratus*, at Santa Catalina Island, CA. Master's thesis, California State University, Northridge. 70 pp.

McFarland. W.N., E.B. Brothers, J.C. Ogden, M.J. Schulman, E.L. Bermingham, and N.M. Kotchian-Prentiss. 1985. Recruitment patterns in young French grunts, *Haemulon lavolineatum* (family Haemulidae), at St. Croix, Virgin Islands. U.S. Fish. Bull., 83(3): 413–426.

Middaugh, D.P. 1981. Reproductive ecology and spawning periodicity of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). Copeia. 1981(4): 766–776.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dep. Fish Game, Fish Bull. 157:249 pp.

Miller, J.A. and A.L. Shanks. 2004. Evidence for limited larval dispersal in black rockfish (*Sebastes melanops*): Implications for population structure and marine reserve design. Can. J. Fish. Aquat. Sci., 61:1723–1735.

Neilson, J.D. and G.H. Geen. 1982. Otoliths of Chinook salmon (*Oncorhynchus tshawytscha*): daily growth increments and factors influencing their production. Can. J. Fish. Aquat. Sci., 39: 1340–1347.

Shanks, A.L. 2009. Pelagic larval duration and dispersal distance revisited. Biol. Bull., 216:373–385.

———, B.A. Grantham, and M.H. Carr. 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecol. Applic., 13(1): 159–169.

——— and G. Eckert. 2005. Life-history traits and population persistence of California current fishes and benthic crustaceans; solution of a marine drift paradox. Ecol. Monogr., 75:505–524.

Sears-Hartley, J. 1994. Age, growth, and early life history of *Paralichthys californicus* derived from otolith microstructure. Master's thesis, California State University, Northridge. 54 pp.

Victor, B.C. 1986. Duration of the planktonic larval stage of one hundred species of Pacific and Atlantic wrasses (family Labridae). Mar. Biol., 90:317–326.

Watson, J.R., S. Mitarai, D.A. Siegel, J.E. Caselle, C. Dong, and J.C. McWilliams. 2010. Realized and potential larval connectivity in the Southern California Bight. Mar. Ecol. Progr. Ser., 401:31–48.

———, C.G. Hays. P.T. Raimondi, S. Mitarai, C. Dong, J.C. McWilliams, C.A. Blanchette. J.E. Caselle, and D.A. Siegel. 2011. Currents connecting communities: nearshore community similarity and ocean circulation. Ecology. 92(60): 1193–1200.